AD 257 371

U. S. NAVAL AIR DEVELOPMENT CENTER

JOHNSVILLE, PENNSYLVANIA

Aviation Medical Acceleration Laboratory

NADC-MA-6044 11 April 1961

Some Body Displacements and Medical Effects of Lateral Accelerations during Navy Centrifuge Simulation of Ejection Capabilities from the Army AO Aircraft

Bureau of Naval Weapons
Project TED ADC RAAE-23012 Final Report

DEPARTMENT OF THE NAVY
U.S. NAVAL AIR DEVELOPMENT CENTER

U.S. NAVAL AIR DEVELOPMENT CENTER

JOHNSVILLE, PENNSYLVANIA

Aviation Medical Acceleration Laboratory

NADC-MA-6044 11 April 1961

Some Body Displacements and Medical Effects of Lateral Accelerations during Navy Centrifuge Simulation of Ejection Capabilities from the Army AO Aircraft

Bureau of Naval Weapons
Project TED ADC RAAE-23012 Final Report

Carl C. Clark

Prepared by: Carl C. Clark, Ph.D.*

James D. Hardy

Approved by: James D. Hardy, Ph.D.
Research Director, Aviation Medical Acceleration Laboratory, and Professor of Physiology, University of Pennsylvania

F K Smith

Approved by: F. K. Smith, CAPTAIN, MC, USN
Director
Aviation Medical Acceleration Laboratory

* Present Address: Life Sciences Dept., Engineering Division
The Martin Company, Baltimore 30, Md.

SUMMARY

A Martin-Baker Mark J5 seat, used in the Army YAO-1 "Mohawk" prototype aircraft, was mounted facing tangentially on the Navy Johnsville Human Centrifuge at a radius of 41 feet from the centrifuge center. A beam was installed 12.5 inches laterally from a plane through the seat center to the subject's upper right, simulating the canopy beam of the aircraft past which the pilot must clear on an ejection. Motion picture cameras centered in the vertical plane through the beam viewed the subject from the front and from the top (Bureau of Medicine and Surgery Technical Film Report Med. 7-60). Centrifuge runs with four subjects, one wearing a life vest and one a heavy flight jacket and life vest were filmed at 2 G, 3 G, 4 G (3 subjects), and 5 G (1 subject) of radial acceleration. Seat pan heights were not adjusted for the individual subjects. The restraint harness was worn in a very tight condition. The Martin-Baker leg restraint was worn in the flight condition, providing some lateral leg restraint. For steadily applied lateral loads, lateral displacement of the pilot is such as to make questionable, safe ejection past the canopy beam at 2 G_y. With additional equipment on the pilot inside of the restraint harness, lateral displacements will probably be increased. For steadily applied lateral loads above 2 G_y, lateral displacements of the pilot would preclude safe ejection. Except when bulky equipment is worn, shoulder displacements are minimally damped, reaching maximum values essentially synchronously with peak G. At 4 G_y the head may be tipped involuntarily under the canopy beam after several seconds at peak G. At 5 G_y the head is further tipped involuntarily; the one subject experienced a scleral hemorrhage on this run.

ACKNOWLEDGMENT

Special appreciation is expressed for the participation in this project of Capt. Hugh West, USMC, and LCDR Merton Short, USN, as subjects, and of Capt. William Augerson, MC, USA, as one of the medical officers, as a subject, and as a doctor with continuing enthusiastic concern for problems of acceleration.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

INTRODUCTION

The Grumman Aircraft Engineering Corporation is building for the Army the AO-1 "Mohawk" all weather, twin turbo-prop aircraft designed to operate from small, unimproved fields for purposes of tactical observation (Figures 1 and 2). This aircraft has a maximum speed (at 5000 ft altitude in level flight) of about 280 knots and the capability of landing or taking off over a 50-ft obstacle within 800 to 1000 ft) (1). The prototype YAO-1 Mohawk made its first flight in April, 1959, one of nine prototype aircraft which have been built to allow an accelerated test program. The aircraft is now undergoing tests by the Army, Navy, and Marine Corps at the Naval Air Test Center (NATC), Patuxent River, Maryland.

The aircraft utilizes the Martin-Baker Mark J5 ejection seat, to allow safe ejection at all altitudes of the aircraft in the speed range of 60 to 450 knots. Pilot restraint is by means of a torso harness attached by "rocket-jet" fittings to the shoulder straps which in turn attach to the seat at a single fitting between the shoulder blades, by a lap belt, used in preference to "rocket-jet" fittings at the waist of the torso harness, and by leg snubbers which pull the legs in to the seat as it starts up the ejection rails (Figure 3). In this experiment, the torso restraint harness and the lap belt were worn in a tight manner, considerably tighter than would be the case for casual flying but appropriate under conditions of possible emergency. The seats, which have a canopy-shattering bumper on the top, may either be ejected after the canopy is jettisoned by means of a separate control, or they may be fired through the canopy. They must clear canopy support beams, which are not jettisoned, located 12.5 inches on either side of a plane through the seat center.

Prior to the manufacturer's spin tests of the aircraft in 1959, the question was raised as to whether the pilot experiencing the lateral loads of the spin might slide under one of these canopy beams, jeopardizing his safe ejection. A plexiglass barrier was installed beside the pilot to prevent his sliding laterally. It was found that lateral loads during the spins were so low, estimated at 0.3 G_y (2), that this barrier was subsequently removed. Austin (3) presents accelerometer tracings of a spin on an F8U-1, showing 1 G_y maximum at the pilot's seat. He also reports 0.3 G_y as the maximum in a spin of an F4D-1.

More recently, with the aircraft undergoing testing by the military pilots, the question has again been raised as to whether the pilot or observer, experiencing lateral loads of more extreme maneuvers, following for example, the loss of a wing due to enemy action, might slide

Figure 1. A photograph of the Grumman YAO-1 "Mohawk" Army observation aircraft, prototype of the AO-1 (Courtesy of the Grumman Aircraft Engineering Corp.)

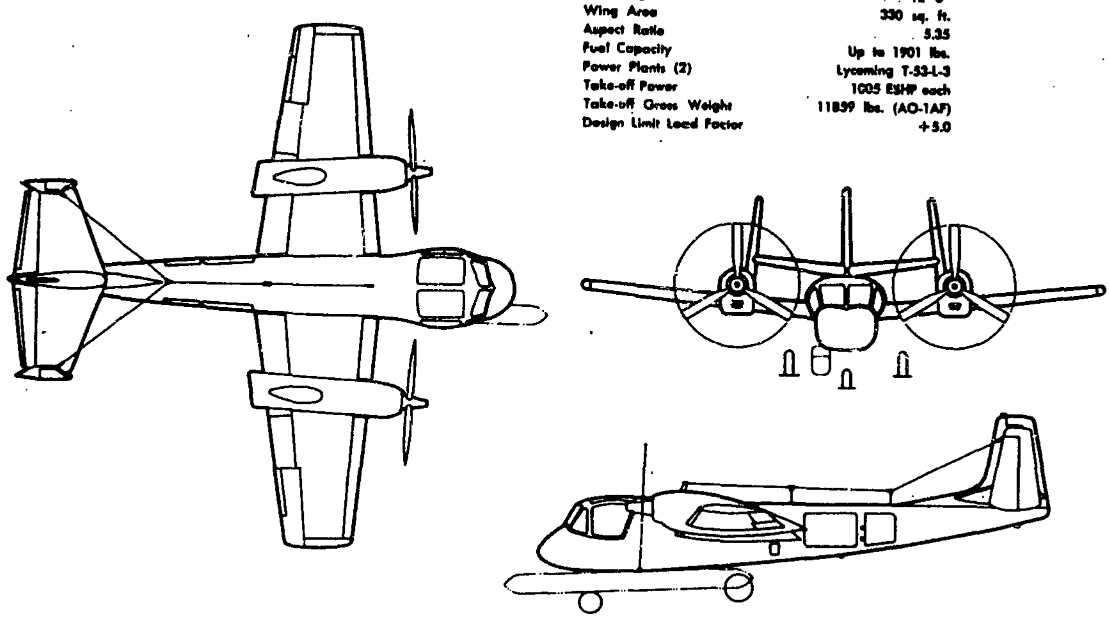

Figure 2. Three diagramatic views of the AO aircraft showing the canopy beams. (Courtesy of the Grumman Aircraft Engineering Corp.)

Figure 3. LCDR Merton Short in the Martin-Baker Mark J5 seat and restraint system on the centrifuge, wearing a life vest, prior to run 14. The simulated canopy beam, 12.5 inches outboard of the vertical plane through the seat center, is seen to the pilot's upper right, above the grid of one inch squares. The pilot holds a "stop-the-run" button in his left hand.

under the canopy beam, jeopardizing safe ejection. Dahms and Ferguson (4) have calculated a lateral load of 4 G_y dropping back to less than 1 G_y in 0.4 seconds, then oscillating in the range of $\pm$ 1 G_y for the two additional seconds of the calculation, for an F9F-6 losing one wing on an 11 G pull-up following a -10°/sec stabilizer deflection at a speed of 778 ft/sec at 3000 ft altitude. In the same period of time the normal load builds up to -19 G_z. These authors also present acceleration time histories calculated for the pilot's head position from accelerometer recordings of an F8U-1 in flight following a wing loss and prior to crash, showing peaks of -3, +10, +13, +2, -5, and +2 G_y in the 7.5 sec of the recording, with a time above 1 G_y of about 0.25 sec for each peak, and with additional peaks in the range of $\pm$ 1 G_y. For the YAO aircraft, the seat will clear the aircraft 0.02 seconds after initiating ejection.

Project TED ADC RAAE-23012 was therefore initiated by the Bureau of Naval Weapons with the Naval Air Development Center to determine the displacements of the pilot while experiencing lateral loads through 5 G, on the Johnsville centrifuge, using a seat supplied by the Grumman Aircraft Engineering Corporation.

ACCELERATION TERMINOLOGY

The acceleration terminology used in this report emphasizes the physiological reactions on the pilot. For a 2 G acceleration, if the heart moves downward in the chest we speak of this as +2 G_z, as in a pull-up. The negative G of an outside loop would cause the heart to move upwards, designated -2 G_z. In the upright position at rest we are experiencing +1 G_z due to gravity. Catapulting of the aircraft forces the heart back in the chest at perhaps +5 G_x. An arrested landing throws the heart forward in the chest at perhaps -6 G_x. (There are also normal and lateral loads developed at the same time (5).) When the heart is thrown to the left, by a yawing turn to the right, we may experience +1 G_y. When the heart is thrown to the right by a left yaw, we may have -1 G_y. We refer to these accelerations experienced by the pilot as "physiological accelerations", to distinguish them from the various acceleration terminologies and various sites of measurement used in aircraft. In this experiment, the heart was thrown to the right; the physiological accelerations were therefore -G_y. However, because of the approximate lateral symmetry of the human, it is expected that muscle capabilities for lateral loads up through 5 G_y would be equivalent for either the left or right direction of acceleration.

THE CENTRIFUGE INSTALLATION

The Martin-Baker Mark J5 seat was installed in the forward-facing position transverse to the centrifuge arm at a 41-foot radius from the centrifuge axis of rotation (Figure 4). A beam simulating the canopy beam was installed 12.5 inches outboard of the seat center, in the vertical plane one inch outboard of the edge of the G meter as seen in Figure 3, and also in the front view motion picture frame (Technical Film Report Med 7-60). The front view motion picture camera was centered in this canopy beam plane to reduce parallax errors and included in its view a vertical grid of one-inch squares, with every fifth inch accentuated. The top view camera (Figure 4) was also centered in the vertical plane through the simulated canopy beam. The cameras were run simultaneously. Since the load seemed so mild, motion pictures were not taken during the 1 G_y lateral load runs. A remotely-operated robot 35 mm color still camera was operated periodically. A Dage television camera (Figure 4) also viewed the subject, with closed circuit TV monitor displays for the Project Officer and the Medical Officer. Since there was a delay in film processing, preliminary results of the experiment were judged from the television views, which also provided reassurance in addition to voice communications, of the subject's condition and actions. The voice communications were recorded on plastic discs.

The pilots wore the torso harness provided by Grumman, properly adjusted. Unfortunately, seat pan height adjustments of up to 5 in. were not provided. The pan was in the fully elevated position, correct for Subject 2 but too high for the other three subjects. The result was that the single attachment point for the shoulder straps, instead of being properly at the top of the shoulders, was below the top of the shoulders for the taller subjects. With torso flexion under acceleration, this might allow greater lateral motion of the shoulders. Indeed, the tallest subject who was also wearing the bulkiest equipment, did have the greatest displacements under lateral loads. However, the second subject's displacements under lateral loads were closely comparable to those of the other two subjects.

Foot supports were provided, approximately but not precisely in the positions of the rudder pedals. The Martin-Baker leg restraints, attaching just below the knees, were used for runs 5 - 18. No attempt was made to simulate the retraction effect of these restraints, which occurs as the seat goes up the ejection rails. Because of the crossed-tie attachments to the seat (Figure 3), the restraints do provide some lateral support for the legs even in the flight condition.

Brief pre- and post-run medical examinations of the subjects were carried out. Electrocardiograph recordings were not used; medical monitoring during the runs was provided by voice communication and television view. The subject held a "stop the run" button in his left hand (Figure 3), which would automatically stop the centrifuge when actuated.

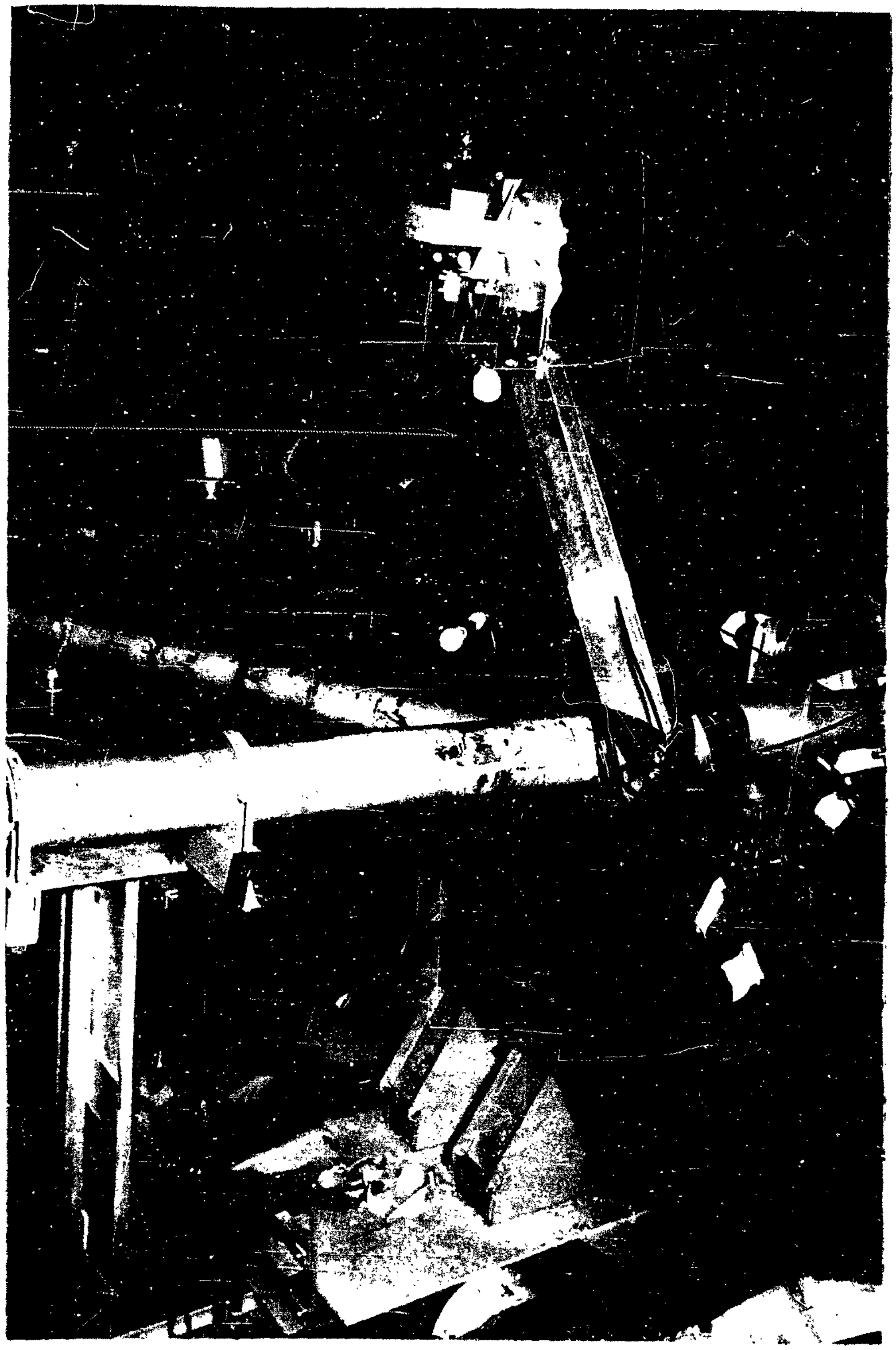

Figure 4. The centrifuge seat and photographic installation. Both the top view and the front view motion picture cameras are centered in the vertical plane through the canopy beam. A television camera, for remote monitoring of the pilot, and a robot still camera are also shown.

The centrifuge was brought up to the appropriate angular velocity, to provide the desired lateral G, by cam control in 12.5 sec. For most runs it was held at peak G for 10 sec, then brought to a stop in 6 sec by automatic actuation of the "normal stop" button. Run 2 was 18 sec at peak G; run 3 was 15 sec. Runs 5 and 18 were stopped by the subjects before the 10-sec period was completed. Since the seat was directly mounted on the centrifuge arm, not on any free-swinging carriage or in a gimbal system, the 1 G_z downward vector of gravity continued to act in this direction throughout the runs. Tangential acceleration components, during the acceleration or deceleration of the centrifuge, were less than 0.5 G_x in magnitude. Eighteen runs, with four subjects, were made on 10 June 1960.*

RESULTS AND DISCUSSION

Body Displacements Effects. Table I summarizes the observations of head and shoulder displacements under lateral loads, as read from the motion pictures, Technical Film Report Med 7-60. Clearances were read of the right side of the helmet and of the right shoulder seam, with the arms down, from the vertical plane below the simulated canopy beam after reaching peak G. Reading error may be as much as $\pm$ 0.5 inches. Because of the variations of the subject's arm positions, displacements were measured of the shoulder "seam" position, i.e., approximately at the acromion process of the scapula. In general the arms projected several inches beyond this position, although with training they could be pulled in toward the seat center prior to ejection. Even with the arms pulled in, the head of the humerus and the muscle does project an additional inch or so beyond the "seam" position. It is also noted that with a lateral deflection of the spine, due to a greater shoulder displacement than hip displacement, the upward jolt of the ejection seat might be expected to further increase the shoulder displacement.

It can be seen from Table I that shoulder clearance under the simulated canopy beam is marginally adequate, for the first three subjects at a lateral load of 2 G_y. All subjects needed additional drilling to hold their arms in at their sides even at this load. For the fourth and tallest subject, who was also wearing the bulkiest equipment, the shoulder would

---

* Observers of these runs were Major Frank Pfeifer, USA, presently at NATC testing the YAO, Ralph Donnell, Grumman test pilot of the YAO, and Nicholas Soley, Grumman Seats and Survival Section.

TABLE I

RUN NUMBER AND INCHES OF CLEARANCE OF THE SIDE OF THE HELMET AND OF THE SHOULDER SEAM INBOARD OF THE CANOPY BEAM DURING LATERAL LOADS

Subject	(See Ref. 6 for Percentiles) Height Weight	At Rest	Lateral Loads				
			1 G	2 G	3 G	4 G	5 G
1. Dr. Carl C. Clark Reference 6:	70.5 inches 162 lbs. 70 percentile 50 percentile Side of helmet clearance Shoulder seam clearance	 9 in. 4	Run 1 *1	2 *2 6 1.5	3 4 0.5	4 *3 1.5 -1	5 *4 0 -1.5
2. Capt. Hugh West USMC	68.5 inches 124 lbs. 40 percentile 1 percentile Side of helmet clearance Shoulder seam clearance	 9 in. 6	Run 6	7 7 1.5	8 3 0	9 *5, 10 *6 -2, -2 -1.5, -1.5	
3. LCDR Merton Short	69 inches 165 lbs. 50 percentile 55 percentile Side of helmet clearance Shoulder seam clearance	 9 in. 6	Run 11	12 6 1.5	13 2 0.5	14 *7 -1 -1	
4. Capt. W. Augerson MC, USA	72 inches 168 lbs. 90 percentile 55 percentile Side of helmet clearance Shoulder seam clearance	 9 in. 5	Run 15 *8	16 3 0	17 *9, 18 *10 -2, -1 -1, -1		

* NOTES

*1. The 1 G lateral load runs were not photographed.

*2. During the 1 and 2 G runs the subjects tended to tip their heads to the left, possibly an unaware response to the oculogravic illusion in addition to a response to resist the body displacements.

*3. At 4 G, the head is involuntarily turned outboard (to the right) and the chin is pushed down toward the collar bone.

*4. This is the first run with leg restraint, used for all subsequent runs. The subject stopped the run after 2 sec at 5 G due to feelings of fullness in the face.

*5. In this run the subject did not attempt to reach the face curtain.

*6. In this run the subject reached in the vicinity of the face curtain.

*7. In this run the subject wore a life vest, Marks 2 (Mae West). See Figure 3.

*8. This subject wore a heavy flight jacket, a life vest, and a helmet with a visor and oxygen mask.

*9. The subject stopped this run due to feelings of excessive lateral motion.

*10. The subject attempted by even more vigorous splinting (pushing hard against the rudder pedals and seat back) to prevent lateral motion.

contact the canopy beam on ejection with a lateral load of 2 G_y. At 3 G_y, the shoulders of all subjects would probably contact the canopy beam. The helmet of the tallest subject, to which an oxygen mask was attached, also was forced under the canopy beam. At 4 G_y, the helmets of two additional subjects passed under the canopy beam. At 5 G_y the helmet of the final subject passed under the canopy beam.

Shoulder Motions. Shoulder displacements under lateral loads are determined by the restraints. For these restraints, lateral loads of 3 G and above became quite uncomfortable by the time peak G was reached, with a feeling of supporting the entire body weight on the right clavicle. All subjects had bruises across the right clavicle which lasted for several days. To prevent inadvertent actuation of the shoulder harness take-up reel release, which occurred in a previous study, the release was bolted in the locked position.

Hip Motions. Hip displacements under lateral loads were somewhat less than the shoulder displacements. The modified Martin-Baker restraint for the YAO Aircraft, using a lap belt, is an improvement over the previously studied Martin-Baker Mark G5 seat (7), which has "rocket-jet" fittings at the waist to the integrated torso harness and sufficiently long straps to the back to allow the subject to swing upward under $-G_x$ loads (and this would also occur under $-G_z$ loads) and swing to the side under lateral loads. With even the improved restraint of this study, the hip slid under the canopy beam (approximately a 5-inch displacement) at 2 G_y for subject 4, at 3 G_y for subjects 1 and 2, and at 4 G_y for subject 3. In run 18 the subject attempted by vigorous pushing on the foot pedals and against the seat back to prevent his lateral motion at 3 G_y. Although he was successful in reducing his head displacement by one inch, his hip and shoulder displacements were unaffected. A contour couch seat or other lateral supports (8) would probably be required to eliminate these lateral motions. To prevent inadvertent release of the lap belt, the release handle was taped in the locked position during this study (Figure 3).

Head Motions. It had been expected from earlier work (9) that involuntary, and possibly uncomfortable head motions would occur at 4 G and above. It is noted from the films that at 3 G_y and above the subjects tended to yaw their heads to the right, a more comfortable and partially involuntary accommodation to the lateral load than a rolling of the head to the right, a motion limited to a lesser angle. At 4 G_y and 5 G_y this involuntary yawing rotation of the head was more apparent, and the chin was forced down toward the right clavicle, but without particular discomfort.

Arm Motions. Arm motions were quite possible even at 5 G_y, although the pilots tended to question their capabilities and not attempt to reach about until prompted to do so. Understandably, the lateral motion during centrifugation give one the great desire to simply "hang on". It might be appropriate, now that certain flight vehicles are moving at higher speeds, and therefore are capable of larger decelerations in emergencies, and for longer durations, that all fleet pilots be indoctrinated on a centrifuge to experience for themselves the quite remarkable range of human motion capabilities while under acceleration (7).

Because of the displacements to the right under lateral load, it was considerably easier to reach the face curtain with the left hand than with the right. Indeed at 4 G_y and above because of the head being deflected toward the right shoulder, it was very difficult to raise the right arm to the face curtain. With lateral displacements, the pilot may have to feel for the small face curtain ring of the Martin-Baker seat. The larger bi-lobed ring of the A3J face curtain for example would probably be easier to reach. Face curtain actuation requires a force of approximately 20 lb, a force capability not tested in this experiment but probably possible for the subjects once at least one hand was on the face curtain ring. The curtain draws out approximately 17 in.; under the lateral loads this may be enough to cause the elbow to swing outboard under the canopy beam at 2 G_y and above, an aspect also not directly studied in this experiment. In a previous study (10) involving $+G_x$ and $-G_x$ and $+G_z$ accelerations, one to six sec were required to initiate ejection by means of the face curtain, a time which included that required to cut the throttle and draw the feet back into ejection seat stirrups.

All subjects could successfully touch the D-ring between the legs, even during the run up to 5 G_y. The ring was not actually pulled as part of this experiment. It is Martin-Baker intent that the actuation travel be about 4 to 4.5 in. with a force required of 45 to 60 lb (11). Law has stated, however, (11) that he has measured a D-ring force of 130 lb of certain seats, required to initiate ejection, attributed to the complicated routing of the actuation cable. In the previous work here with the Martin-Baker G5 seat (7), the D-ring cable "continued to foul more and more often during the course of the investigation", so that no single value for the force required to operate the D-ring could be given. Law stated (11) that the Air Crew Equipment Laboratory (ACEL) is working on an alternate means of D-ring cable connection to reduce and make more uniform the forces required for D-ring actuation, and that a report on this is in preparation. Beckman (12) points out that the ejection seat is not intended for repeated ejection use. It must operate the first time but, depending on the adequacy of inspection procedures to determine proper operation without partial use, it may not be necessary for it to be designed to withstand repeated use. With motion of the hips to the right of several inches under lateral loads, it becomes necessary to partially raise the left leg to reach the D-ring. It is uncertain, although still considered possible, that the D-ring could be pulled out 4 in. with a force of 60 lb. However, if the accident included a normal component greater than 2 G_z, it would probably not be possible to lift the leg and pull the D-ring.

Leg Motions. The lateral loads caused the legs to swing to the right under the canopy beam even at 2 G_y, but the retraction of the legs by the leg restraint would serve to pull the legs in. Earlier concern that under large lateral loads (4 G_y or more) the knee might hook around the seat pad is relieved by observing that the leg restraint in the flight condition still provides sufficient support to probably prevent the knee from swinging this far. It was possible to take the feet off the pedals then get them back on again at 2 G_y. This was not attempted but still might have been possible at 3 G_y. In a previous study (10), only one of five subjects at -3 G_x could get both feet back from the rudder pedals onto the F9F ejection seat stirrups; no one could do this at -4 G_x, nor could it be done at +6 G_z.

Equipment Effects. While preparing for these tests, ACEL recommended that 5 and 95 percentile subjects with appropriate minimum and maximum personnel equipment be used. Table I gives the heights and weights and percentile values (6) of the subjects, and the notes indicate the equipment worn by two subjects in addition to the light weight flight suit worn by all subjects. The addition of the life vest under the torso harness provided padding under the straps, making the 4 G_y run no worse for the subject than the 3 G_y run. The harness was tight and the life vest equipment was not particularly compressible; displacements under lateral load did not show any large increase. On the other hand, Subject 4 wore a heavy flight jacket, which was compressible, under the torso harness; this may have contributed to his distinctly larger displacements under lateral loads than the other subjects. This subject also stated that with this bulky equipment in the restraint harness it was not possible to touch his elbows together prior to reaching for the face curtain; the bulky equipment would increase the likelihood of the arm being outboard and under the canopy beam when the ejection is initiated under lateral load. He also wore a helmet with a visor and an oxygen mask; the side of his helmet was displaced more than his shoulder at 2 G_y and 3 G_y, and more than the helmets of the other subjects. The heaviest subject studied weighed 168 pounds; this experiment barely touched on the effects on distributions of subjects and equipment.

MEDICAL EFFECTS

The Oculogravic Illusion. Subject 1 clearly sensed and reported the oculogravic illusion developed as the centrifuge came up to speed. In previous work on a free-swinging carriage or in a moving gimbal system, the illusion was obscured by sensations of actual motions or by other illusions, notably the Coriolis illusions and centrifugation after-effect illusions. As the centrifuge came up to speed, to give 1 G radial acceleration, the resultant acceleration vector shifts from a roll angle of 180°, i.e., down, to 135°, i.e., to the lower right. The illusion, in response to this new resultant, "down" direction is that the centrifuge hub and arm rises, so that the sensation with the eyes open is of travelling around in the centrifuge chamber on the surface of a cone. At above 1 G radial, the sensation was as if the subject was stationary, but rolled outboard, and that it was the chamber that was rotating, not the subject, an illusion previously described (13). The illusion abated promptly as the centrifuge slowed, with no after effects. The illusion was that the hub and arm tipped upward to the left about 30° instead of the full 45° shift of the resultant acceleration vector. At higher G levels the sense of tipping increased to perhaps 45° at 5 G radial, when the resultant acceleration vector had tipped 78°. It may be that the illusion magnitude was reduced by the unaware tipping of the head to the left. At 2 G radial for example, the films clearly show subject 2 tipping (rolling) his head about 45° to the left; when questioned, he reported no sensation of rotating on the centrifuge in other than a horizontal plane, that is, he was not aware of an oculogravic illusion, perhaps because of this compensatory head rotation. This illusion augments the sensation of lateral displacement and contributes to the subjects' desire to just "hold on". If the lateral acceleration were due to a yawing angular velocity to the left, the pilot sensing the illusion would feel that he had rolled to the right and might make a left roll control input. In this case, this control would improve the flight situation. But in general, pilot control in response to illusion sensations cannot be expected to improve the flight situation.

Bruises and Petechiae. In these runs, bruises were produced over the right clavicles of all subjects. But petechiae, or small skin hemorrhages of pencil-dot size, were seen only about the right orbit and the right temple of the subject who experienced $-5\ G_y$, and only a few of these. Petechiae may be expected when local capillary blood pressures exceed their usual values above the local tissue pressure by 100 to 150 mm of the mercury for a few minutes (9). This is equivalent to 120 to 200 G-cm of blood column. For hemorrhages produced by lateral acceleration with the pressure effects involving indirect circulatory routes from the left arm to the right cheek for example, the peaking of pressure in the right cheek would expectedly be slightly delayed with respect to the peaking of the acceleration. For accelerations of a few seconds duration, blood columns of more than 130 to 200 G-cm would be expected before petechiae would occur. Under lateral G with the head far over on the right shoulder, about

20 in. or 50 cm separated the left arm and the right cheek. At $-4\ G_y$, or 200 G-cm of blood column, perhaps a few minutes would be required to observe many petechiae; a very few were observed on Subject 1 only in these runs with only 10 sec at peak G. At $-5\ G_y$, or 250 G-cm of blood column, a few more petechiae were observed with only 2 sec at peak G.

Scleral Hemorrhage and Headache. With Subject 1, the local circulatory over-pressures were sufficiently apparent even on the $-4\ G_y$ run to be observable from the windows of the centrifuge chamber as the centrifuge rotated; the right temporal artery was seen to be engorged and obviously pulsating. The right side of the face became flushed; after the $-4\ G_y$ run the subject reported a warm feeling on the right side of the face, and more sweat here than on the left side or on other parts of the body. This condition persisted as the $-5\ G_y$ run started. The right eye was slightly bloodshot. The $-5\ G_y$ run was stopped by the subject 2 sec after reaching peak G, or 14.5 sec after the centrifuge started, due to feelings of fullness of the right side of the face. After the run, more of the face felt flushed. The right temple did not feel as uniquely flushed. A scleral hemorrhage 10 mm wide by 3 mm high had occurred in the lower margin of the right eye. While upright, there was no headache; the slight dull sensations were attributed to the helmet contact areas. The vessels of the right temple continued to be engorged and throb for perhaps 30 minutes after the run. Fundiscopic examination revealed no retinal hemorrhage.

During the first night only, it felt as if there were sand in the lower margin of the right eye. The next day a slight dull sensation, not sufficient to call a headache, remained, with a slight feeling of fullness of the right parietal area, something like but of less intensity than the sensation of having water in the right ear. In attempting to devise means to quantitate this effect, it was found that getting on the knees and touching the top of the head to the floor, i. e., by increasing cerebral vascular pressure by about 50 cm of blood or 40 mm of mercury, that a sharp pain of perhaps 5 dols (14) developed in about 2 sec, then abated in about 5 sec. This effect continued through the succeeding day. The following morning on arising, 44 hours after the run, the effect was gone, but was back by 10:00 A. M. and continued through the day, accompanied by a dull headache still with this slight feeling of fullness in the right parietal area. After 68 hours, the effect was gone although a slight dull feeling, no longer a headache, remained for an additional day. After one week, the hemorrhagic area was slightly enlarged. After two weeks the eye appeared essentially normal. There was no visual defect attributable to this scleral hemorrhage.

It has been suggested by Augerson (15) that the local flushing effect is related to a local histamine reaction in addition to the circulatory over-pressures. A similar flushing was noted in the Mercury "tumble" runs in which the subject was abruptly rotated from $+G_x$ to $-G_x$, simulating the escape rocket acceleration followed abruptly by a drag deceleration (16). Scleral hemorrhages have been observed in simulations of advanced aircraft catapults (17) involving $+G_x$ but with an aircraft seat tipped back and, in the recent simulations of flat spins of the A3J, these involved some $-G_z$ and also $-G_x$ so that the head came further forward than with previous studies with this acceleration vector. It is expected that tightly closing the eyes with squinting would provide some protection against scleral hemorrhages.

It is suggested that for subsequent centrifuge or airborne studies of the type in which scleral hemorrhages might occur that transillumination of the sinuses also be applied to attempt to determine whether, as expected, hemorrhages occur there as well. The tympanic membrane should also be examined.

It is concluded that there is a possibility of developing scleral hemorrhages whenever there is more than 200 G-cm or 80 G-in. of blood column along the resultant G vector above the eye for several seconds or longer. The seated pilot, who may have about 36 in. of blood column from his feet to his eyes along the z-axis projection, would expectedly risk scleral hemorrhages in maneuvers involving more than 2 negative G (or $-2\ G_z$). Coburn (18) reports two cases he has seen of scleral hemorrhages following inverted spins. An inverted spin of an FJ4 was measured to give $-1.6\ G_z$, with about 20 sec above $-1\ G_z$ (4); more severe inverted spins are quite possible. Beckman (19) points out that stunt pilots, after a period of practice buildups to increasing negative G, extending over two or three months or more, can tolerate up to $-5\ G_z$ without developing scleral hemorrhages. Training begins in the spring for stunt shows of the summer; the tolerance is lost if negative G practice is not maintained through the winter. One stunt pilot found some benefit in maintaining tolerance when not flying by periodically hanging by his knees, head down. Scleral vessel fragility can evidently be reduced by repeated exposures to over-pressures. Beckman also notes that patients who have been in bed for long periods may develop petechiae on the feet when first standing up; the vessels have lost their tolerance for the hydrostatic head of the upright position so that even the 70 G-inches of blood column, normally tolerated by the feet (at 1 G standing up) would produce petechiae.

<u>Respiration Effects.</u> During the forward tumble runs (16) in which resultant acceleration rapidly rotated from $+G_x$ to $-G_x$, and more particularly in the lateral tumble runs, in which the resultant acceleration vector rapidly rotated from $+G_x$ to $-G_x$ and $-G_y$, ending with a resultant

acceleration vector with a yaw heading of 50° through the subject's body, there was some feeling of shortness of breath after the run (intense with some subjects), measurements of a temporarily reduced vital capacity, and in some subjects x-ray evidence of slight atelectasis. Subject 1 of this AO program therefore made vital capacity measurements before and after his runs but found no significant change. Moreover, there were no subject comments as to respiratory difficulty during these runs. Evidently with the lower G levels and the more gradual onset of the lateral accelerations used in this experiment, in comparison to the lateral tumble experiment, respiratory difficulties do not develop.

A Blurred Vision After-Effect. Subject 3 reported a blurring of vision in the right eye immediately following his last run. This was described as a difficulty in bringing the eye to focus. Post-run examination showed equal pupils and reactions to light. Fundoscopic examination showed no retinal displacement or hemorrhage. The subject's near-vision, reading newspaper type, was "normal" but distant vision was apparently decreased. Visual fields by confrontation were normal and eye tone was bilaterally firm, (observed digitally). Approximately 15 minutes post-run, the subject reported that he had clear vision and could read near and distant print with ease, and eye examination continued negative. Three weeks post-run the subject reported that his vision remained normal.

The exact cause of this altered vision is not certain. It may be similar in origin to the blurred vision experienced in high transverse accelerations. It is believed that these experiences are related to deformations of the globe relative to the cornea. Until a thorough study of the physiology of vision under acceleration is undertaken, the significance of such experiences will be speculation.

IMPLICATIONS FOR EJECTION

It must be emphasized that this experiment involved only steady or gradually changing (less than 0.5 G/sec) accelerations. Although the body is displaced, its motions are so slow that accelerations measured on the body would presumably be very close to those measured on the seat. The damping of the head motion, presumably due to subject straining to hold the head centered, is quite apparent from the films; several seconds at peak G are required before the head attains its full displacement. The shoulders on the other hand appear to reach full travel simultaneously with peak G, except when bulky equipment is worn. For seat accelerations of shorter duration (but with a period still greater than that of body resonance), the body would attain higher velocities with respect to the seat, and would attain greater displacements than with a slow acceleration buildup; accelerations measured on the body would exceed those measured on the seat. This would be true whether the body were restrained but resonating (20) or simply loose in the harness so that it swings out and then is brought up abruptly when reaching the limits of harness travel. We do not know the resonance frequency for lateral vibrations of the man in this restraint system in this seat; a guess would be about 3 cps. For acceleration pulses of shorter and shorter duration (higher frequency) the accelerations of the body would again equal and then be less than the accelerations of the seat.

Grumman representatives are analyzing the acceleration time histories predicted for the AO aircraft following certain emergencies, and will report these directly to the Bureau of Naval Weapons. It is expected that the predicted acceleration frequencies will not exceed 3 cps, except during the times that structural members are failing. The shoulder displacements reported here are therefore reasonable figures to use in the analysis of the effects of such lateral accelerations on the pilot on the assumption that delayed damping effects, (such as the body sliding in the harness, which might have occurred in these studies but would not occur for shorter acceleration pulses) would approximately compensate for the resonance overshoot which might occur with shorter acceleration pulses but did not occur in this study.

In previous work (10) involving $+G_x$ and $-G_x$ and $+G_z$ accelerations, one to six seconds were required to successfully initiate ejection by means of the face curtain, a time which included the time to cut the throttle and draw the feet back on the F9F ejection seat stirrups. In general, less time was required to actuate the D-ring ejection control although acceleration and equipment conditions are described in which neither control could be actuated. In-flight aircraft accidents can involve severe accelerations of the falling aircraft pieces throughout the remaining flight period, depending on aerodynamic conditions of these pieces. Although the cockpit speed will tend to decrease, one cannot properly advise the pilot to delay ejection, even when he is at considerable altitude, on the hope that after the wings and tail have broken off subsequent accelerations will be reduced. On the other hand, following the initial severe accelerations the aircraft may restabilize allowing safe escape if the accident has not involved extensive loss of aerodynamic control surfaces, and indeed involves only the development of instability. It has been surmised that Capt. Apt, in the last flight of the X-2, might have survived if he had not ejected so soon after losing control, for the aircraft after slowing might have regained stability. If the pilot knows that he has lost a complete control surface, it is probably wisest for him to initiate ejection as soon as he can.

In the AO, the crew members are 100 in. forward of the aircraft center of gravity (2). Aircraft maneuver and airborne accident accelerations are primarily generated by rotations rather than by changes of motor thrust or drag. The radii of such rotations depend on aerodynamic as well as on structural center of gravity factors. Mathematical assumptions as to the control surface changes might, or much more likely, might not predict the worst acceleration cases; recordings from actual accidents generally indicate a far greater complexity of motion (4). This time-varying complexity of different acceleration components will further complicate the pilot's task in initiating ejection, an aspect of the simulation not covered by this work. Concern in this project has been for the clearance of the crew past the canopy beam on ejection during lateral loads engendered for example by the loss of a wing due to enemy action or other accident.

Following an accident, the pilot must decide that he will attempt to eject and then, with the Martin-Baker Mark J5 seat (and some other current Navy ejection seats), whether he will reach for the face curtain or the D-ring, either of which may inaccessible under certain conditions. We do not know the criteria pilots use in reaching these decisions, but the choice condition is one in which training, perhaps on a centrifuge, would expectedly aid the pilot in reaching the proper decision, in showing him those conditions under which one or the other ejection actuation device could not successfully be utilized. From an earlier ejection study (7), it was recommended that a single type of ejection control located on either side of the seat bucket or on the arm rests be utilized; however, the face curtain retains its distinct advantage of minimum inadvertent use. The possibility remains, subject to similar reliability or frequency of unintended use considerations, of developing an automatic ejection device which senses hazardous conditions and ejects the pilot automatically, possibly even momentarily delaying ejection (in the YAO if ever over 2 G_y, for example) until acceleration conditions are such that a safe ejection can be made.

The earlier study (7) also led to the recommendation of the development of a six-point restraint system, either side of the shoulders, chest, and lap. With the more recent work on contour couches (8), it is clear that a restraint system could be built to minimize body motions with respect to the vehicle during lateral, jostle, or other acceleration loads, involving a minimum weight seat insert, perhaps made of fiberglass, countour-moulded to the individual pilot. A similar idea has been expressed by Donovan Heinle of the National Aeronautics and Space Administration Ames Research Center. Part of the development work on contour couches has been carried out in cooperation with the Ames Research Center. This seat-restraint system ideally would be shock mounted in such a way as to be isolated from the vehicle for high frequency acceleration components with low amplitudes of displacement, so that body accelerations would be less than those of the vehicle. The restraint should be locked to the vehicle for lower frequency acceleration components with large amplitudes of displacement, at frequencies near the system resonance frequency; for without locking the seat to the vehicle, body accelerations would exceed vehicle accelerations.

CONCLUSION CONCERNING EJECTION

For steadily applied lateral loads in the Martin-Baker Mark J5 Ejection Seat and restraint system in use in the YAO-1 aircraft, lateral displacement of the pilot is such as to make questionable safe ejection at 2 G_y past the canopy beam located 12.5 inches from the seat center, even with the restraint harness tighter than would be the case in general flying. With additional equipment on the pilot inside of the restraint harness, lateral displacements will probably be increased. For steadily applied lateral loads above 2 G_y, this study indicates that lateral displacements of the pilot would preclude safe ejection. The theoretical discussion in the previous section indicates that either body motion damping effects, reducing displacements, or resonance overshoot effects, increasing displacements might occur for the shorter duration acceleration pulses of aircraft in-flight accidents. Until such time as the resonance frequencies and damping of this man-seat-restraint system can be determined, the shoulder displacement values of this study are reasonable predictions of displacements to be expected in aircraft experiencing similar acceleration components.

REFERENCES

1. Grumman AO-1 Mohawk, Brochure PGB-134-4, Grumman Aircraft Engineering Corp., February 1960.

2. Letter from Nicholas Soley, Grumman, to Dr. Clark, AMAL, 24 June 1960, answering questions asked by Dr. Clark.

3. Austin, Frank, LCDR, MC, USN: Physiological Instrumentations for Pilots for Test and Operational Flights in Navy High Performance Jet Aircraft, Naval Air Test Center report presented at the AGARD Joint Meeting of the Flight Test and Aero-Medical Panels, Athens, Greece, May 1959.

4. Dahms, Joseph G. and Samuel T. Ferguson: Forces Imposed on Pilots During Inflight Emergencies, U. S. Naval Air Development Center Report NADC-ED-5813, 2 July 1958.

5. Hannegan, E. A.: Typical Acceleration Loads Imposed on Pilots During Catapulting and Arresting, U. S. Naval Air Test Center Letter Report PTR SI-43108, FT35 - 149, 3 April 1959.

6. Hertzberg, H.T.E. and G. S. Daniels: Anthropometry of Flying Personnel, 1950, Wright Air Development Center Technical Report 52-321.

7. Hill, J. H. and M. G. Webb: Pilot's Ability to Actuate Ejection Controls, U. S. Naval Air Development Center Letter Report TED ADC AE 5205, MA-8, 952, 5 February 1959.

8. Clark, Carl C. and R. Flanagan Gray: A Discussion of the Restraint and Protection of the Human Experiencing the Smooth and Oscillating Accelerations of Proposed Space Vehicles, U. S. Naval Air Development Center Report NADC-MA-5914, 29 December 1959.

9. Clark, Carl C.: Centrifuge Simulation of the X-15 Research Aircraft, U. S. Naval Air Development Center Report NADC-MA-5916, 10 December 1959.

10. Hill, J. H. and J. L. Brown: Comparative Evaluation of a Standard Face Curtain and an Experimental D-ring Located on the Seat Front as Modes of Actuating Ejection During Exposure to Acceleration, U. S. Naval Air Development Center Letter Report TED ADC AE-5205, MA-3, 3585, 5 May 1958.

11. Law, W.; Air Crew Equipment Laboratory, Personal Communication, 30 June 1960.

12. Beckman, E. L., Personal Communication, Aviation Medical Acceleration Laboratory, U. S. Naval Air Development Center, Johnsville, Pa.

13. Gray, R. F. and R. J. Crosbie: Variation in Duration of Oculogyral Illusions as a Function of the Radius of Turn. Aviation Medical Acceleration Laboratory, U. S. Naval Air Development Center, Johnsville, Pa., Report NADC-MA-5806, 22 May 1958.

14. Hardy. J. D., H. G. Wolff and Helen Goodell. Pain Sensations and Reactions. Williams and Wilkins, Baltimore, 1952.

15. Augerson, W., NASA Space Task Group, Personal Communication.

16. Clark, C. C., Navy Centrifuge Simulation of the National Aeronautics and Space Administration Project Mercury Vehicle Program I, Aviation Medical Acceleration Laboratory, U. S. Naval Air Development Center, Johnsville, Pa., Letter Report TED ADC AE-1412, ser 0890 of 7 Oct. 1959 (Confidential).

17. Brown, J. L., H. Ellis, M. G. Webb, and R. F. Gray: The Effect of Simulated Catapult Launching on Pilot Performance, U. S. Naval Air Development Center Report NADC-MA-5719, 31 December 1957.

18. Coburn, K., Personal Communication, Aviation Medical Acceleration Laboratory, U. S. Naval Air Development Center, Johnsville, Pa.

19. Beckman, Edward L.: Effects of Acceleration Upon the Cerebral Metabolism and Cerebral Blood Flow, Phase IV: Some Observations on Negative G Developed in Aerobatics, U. S. Naval Air Development Center Report NADC-MA-5203, 23 April 1952.

20. Cope, Freeman W.: Problems in Human Vibration Engineering, U. S. Naval Air Development Center Report NADC-MA-5902, 6 March 1959.

APPENDIX A

Scene Description of the Technical Film Report Med. 7-60: Navy Centrifuge Simulation of the Army AO Aircraft Ejection Sequence.

1. The YAO-1, prototype of the AO-1, is seen taking off and flying. Note canopy beams which the crew members must clear on ejection.

2. A subject, Dr. Clark, followed by Capt. Augerson, climbs onto the centrifuge and into the seat installation. The torso harness shown was changed before the runs began for the Grumman YAO torso harness. The positions of the front view and top view motion picture cameras are shown.

3. The centrifuge is shown beginning to rotate.

4. Front view of Run 2, $-2\ G_y$ (Dr. Clark). Note the rolling of the head to the left, perhaps in compensation for the oculogravic illusion, and that the shoulder displacement is maximum right at peak G.

5. Top view of Run 2.

6. The centrifuge is seen coming to rest.

7. Front view of Run 3, $-3\ G_y$ (Dr. Clark).

8. Top view of Run 3.

9. Front view of Run 4, $-4\ G_y$ (Dr. Clark). Note the head being forced to the right.

10. Top view of Run 4.

11. The centrifuge is seen starting to rotate.

12. Front view of Run 5, $-5\ G_y$ (Dr. Clark). Note the inability to reach the face curtain with the right hand, because of the head being tipped to the right. The subject stopped the run after 2 seconds at peak G due to feelings of fullness of the right side of the face. He had scleral hemorrhage.

13. The centrifuge is seen coming to rest.

14. Front view of Run 7, -2 G_y (Capt. West). Note the head being rolled to the left, possibly in compensation for the oculogravic illusion.

15. Front view of Run 7.

16. Front view of Run 8, -3 G_y (Capt. West).

17. Top view of Run 8.

18. Front view of Run 9, -4 G_y (Capt. West). No attempt was made to reach the face curtain. Note the delayed forcing of the head to the right.

19. Top view of Run 9.

20. Front view of Run 10, -4 G_y (Capt. West). The right hand was put in the vicinity of the face curtain.

21. Top view of Run 10.

22. Front view of Run 12, -2 G_y (LCDR Short).

23. Top view of Run 12.

24. Front view of Run 13, -3 G_y (LCDR Short).

25. Top view of Run 13.

26. Front view of Run 14, -4 G_y (LCDR Short). The pilot is wearing a life vest, Mark 2.

27. Front view of Run 16, -2 G_y (Capt. Augerson). The pilot is wearing a heavy Army jacket, and has an oxygen mask on his helmet. He is able to take his feet off and then get them back on the rudder pedals.

28. Top view of Run 16.

29. Front view of Run 17, -3 G_y (Capt. Augerson).

30. Top view of Run 17.

31. Front view of Run 18, -3 G_y (Capt. Augerson). The pilots tried, unsuccessfully, to reduce body motion by maximum pushing against the rudder pedals and seat back. Notice that with the bulky equipment there is some damping of the shoulder motion so that maximum shoulder displacement occurs slightly after peak G.

32. Top view of Run 18.

-End-

U. S. NAVAL AIR DEVELOPMENT CENTER, JOHNSVILLE, PA.
AVIATION MEDICAL ACCELERATION LABORATORY

1. Report NADC-MA-6044
2. Project TED ADC RAAE-23012

Some Body Displacements and Medical Effects of Lateral Accelerations during Navy Centrifuge Simulation of Ejection Capabilities from the Army AO Aircraft: by Carl C. Clark, Ph.D., 21 pp., 11 April 1961

Martin-Baker Mark J5 seat, used in the Army YAO-1 "Mohawk" prototype aircraft, was mounted facing tangentially on the Navy Johnsville Human Centrifuge at a radius of 41 feet from the centrifuge center. A beam was installed 12.5 inches laterally from a plane through the seat center to the subject's upper right, simulating the canopy beam of the aircraft past which the pilot must clear on an ejection. Motion picture cameras centered in the vertical plane through the beam viewed the subject from the front and from the top (Bureau of Medicine and Surgery Technical Film Report Med - 7-60). Centrifuge runs with four subjects, one wearing a life vest and one a heavy flight jacket and life vest were filmed at 2 G, 3 G, 4 G (3 subjects), and 5 G (1 subject) of radial acceleration. Seat pan heights were not adjusted for the individual subjects. The restraint harness was worn in a very tight condition. The Martin-Baker leg restraint was worn in the flight condition, providing some lateral leg restraint. For steadily applied lateral loads, lateral displacement of the

U. S. NAVAL AIR DEVELOPMENT CENTER, JOHNSVILLE, PA.
AVIATION MEDICAL ACCELERATION LABORATORY

1. Report NADC-MA-6044
2. Project TED ADC RAAE-23012

Some Body Displacements and Medical Effects of Lateral Accelerations during Navy Centrifuge Simulation of Ejection Capabilities from the Army AO Aircraft: by Carl C. Clark, Ph.D., 21 pp., 11 April 1961

Martin-Baker Mark J5 seat, used in the Army YAO-1 "Mohawk" prototype aircraft, was mounted facing tangentially on the Navy Johnsville Human Centrifuge at a radius of 41 feet from the centrifuge center. A beam was installed 12.5 inches laterally from a plane through the seat center to the subject's upper right, simulating the canopy beam of the aircraft past which the pilot must clear on an ejection. Motion picture cameras centered in the vertical plane through the beam viewed the subject from the front and from the top (Bureau of Medicine and Surgery Technical Film Report Med - 7-60). Centrifuge runs with four subjects, one wearing a life vest and one a heavy flight jacket and life vest were filmed at 2 G, 3 G, 4 G (3 subjects), and 5 G (1 subject) of radial acceleration. Seat pan heights were not adjusted for the individual subjects. The restraint harness was worn in a very tight condition. The Martin-Baker leg restraint was worn in the flight condition, providing some lateral leg restraint. For steadily applied lateral loads, lateral displacement of the

U. S. NAVAL AIR DEVELOPMENT CENTER, JOHNSVILLE, PA.
AVIATION MEDICAL ACCELERATION LABORATORY

1. Report NADC-MA-6044
2. Project TED ADC RAAE-23012

Some Body Displacements and Medical Effects of Lateral Accelerations during Navy Centrifuge Simulation of Ejection Capabilities from the Army AO Aircraft: by Carl C. Clark, Ph.D., 21 pp., 11 April 1961

Martin-Baker Mark J5 seat, used in the Army YAO-1 "Mohawk" prototype aircraft, was mounted facing tangentially on the Navy Johnsville Human Centrifuge at a radius of 41 feet from the centrifuge center. A beam was installed 12.5 inches laterally from a plane through the seat center to the subject's upper right, simulating the canopy beam of the aircraft past which the pilot must clear on an ejection. Motion picture cameras centered in the vertical plane through the beam viewed the subject from the front and from the top (Bureau of Medicine and Surgery Technical Film Report Med - 7-60). Centrifuge runs with four subjects, one wearing a life vest and one a heavy flight jacket and life vest were filmed at 2 G, 3 G, 4 G (3 subjects), and 5 G (1 subject) of radial acceleration. Seat pan heights were not adjusted for the individual subjects. The restraint harness was worn in a very tight condition. The Martin-Baker leg restraint was worn in the flight condition, providing some lateral leg restraint. For steadily applied lateral loads, lateral displacement of the

U. S. NAVAL AIR DEVELOPMENT CENTER, JOHNSVILLE, PA.
AVIATION MEDICAL ACCELERATION LABORATORY

1. Report NADC-MA-6044
2. Project TED ADC RAAE-23012

Some Body Displacements and Medical Effects of Lateral Accelerations during Navy Centrifuge Simulation of Ejection Capabilities from the Army AO Aircraft: by Carl C. Clark, Ph.D., 21 pp., 11 April 1961

Martin-Baker Mark J5 seat, used in the Army YAO-1 "Mohawk" prototype aircraft, was mounted facing tangentially on the Navy Johnsville Human Centrifuge at a radius of 41 feet from the centrifuge center. A beam was installed 12.5 inches laterally from a plane through the seat center to the subject's upper right, simulating the canopy beam of the aircraft past which the pilot must clear on an ejection. Motion picture cameras centered in the vertical plane through the beam viewed the subject from the front and from the top (Bureau of Medicine and Surgery Technical Film Report Med - 7-60). Centrifuge runs with four subjects, one wearing a life vest and one a heavy flight jacket and life vest were filmed at 2 G, 3 G, 4 G (3 subjects), and 5 G (1 subject) of radial acceleration. Seat pan heights were not adjusted for the individual subjects. The restraint harness was worn in a very tight condition. The Martin-Baker leg restraint was worn in the flight condition, providing some lateral leg restraint. For steadily applied lateral loads, lateral displacement of the

pilot is such as to make questionable, safe ejection past the canopy beam at 2 G_y. With additional equipment on the pilot inside of the restraint harness, lateral displacements will probably be increased. For steadily applied lateral loads above 2 G_y, lateral displacements of the pilot would preclude safe ejection. Except when bulky equipment is worn, shoulder displacements are minimally damped, reaching maximum values essentially synchronously with peak G. At 4 G_y the head may be tipped involuntarily under the canopy beam after several seconds at peak G. At 5 G_y the head is further tipped involuntarily; the one subject experienced a scleral hemorrhage on this run.

pilot is such as to make questionable, safe ejection past the canopy beam at 2 G_y. With additional equipment on the pilot inside of the restraint harness, lateral displacements will probably be increased. For steadily applied lateral loads above 2 G_y, lateral displacements of the pilot would preclude safe ejection. Except when bulky equipment is worn, shoulder displacements are minimally damped, reaching maximum values essentially synchronously with peak G. At 4 G_y the head may be tipped involuntarily under the canopy beam after several seconds at peak G. At 5 G_y the head is further tipped involuntarily; the one subject experienced a scleral hemorrhage on this run.

pilot is such as to make questionable, safe ejection past the canopy beam at 2 G_y. With additional equipment on the pilot inside of the restraint harness, lateral displacements will probably be increased. For steadily applied lateral loads above 2 G_y, lateral displacements of the pilot would preclude safe ejection. Except when bulky equipment is worn, shoulder displacements are minimally damped, reaching maximum values essentially synchronously with peak G. At 4 G_y the head may be tipped involuntarily under the canopy beam after several seconds at peak G. At 5 G_y the head is further tipped involuntarily; the one subject experienced a scleral hemorrhage on this run.

pilot is such as to make questionable, safe ejection past the canopy beam at 2 G_y. With additional equipment on the pilot inside of the restraint harness, lateral displacements will probably be increased. For steadily applied lateral loads above 2 G_y, lateral displacements of the pilot would preclude safe ejection. Except when bulky equipment is worn, shoulder displacements are minimally damped, reaching maximum values essentially synchronously with peak G. At 4 G_y the head may be tipped involuntarily under the canopy beam after several seconds at peak G. At 5 G_y the head is further tipped involuntarily; the one subject experienced a scleral hemorrhage on this run.